COMBUSTION: FUEL & SYSTEM EFFICIENCIES

Gas-oil-electricity-or?? Which fuel is best for a specific application? It depends on a number of things such as fuel cost, and the age, size and efficiency of the present heating system, to name a few. Before deciding to replace or upgrade an existing system, we need to consider many of these factors. Perhaps, we should start by reviewing the combustion process.

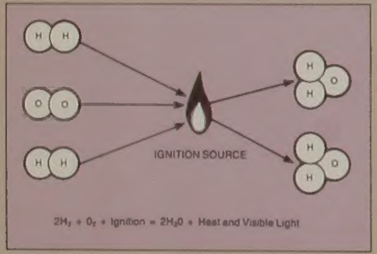
FUNDAMENTALS OF COMBUSTION

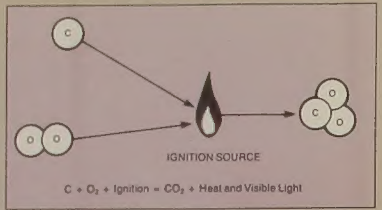
Combustion is a chemical process in which rapid oxidation of a fuel takes place. The result is the liberation of stored energy in the fuel as heat. The commonly used fuels, such as heating oil or natural gas, contain hydrogen and carbon in various compounds. With complete combustion the end products are primarily water and carbon dioxide.

The oxidation is due to the oxygen present in air. In order to have complete combustion the correct proportions of air and fuel must be present. If there is too much fuel or not enough oxygen, combustion will be incomplete and will produce a smokey flame. The normal practice is to supply excess oxygen (or air) in order to assure complete combustion, i.e., to completely oxidize all the hydrogen and carbon in the fuel. As the amount of excess air increases, the efficiency decreases and heat is lost up the flue. For example, 1.52 kilograms of air are needed for the complete combustion of one litre of No. 2 heating oil. If this 1.52 kilograms of air, starting at room temperature, say 20°C, is heated to 200°C and goes up the chimney, approximately 250 kilojoules are lost. If 50 per cent excess air is supplied, 375 kilojoules are lost.

The following diagrams illustrate how the hydrogen and carbon atoms (in the fuel) react with the oxygen atoms (in the air) and an ignition source to produce the end products of heat, light, water vapour and carbon dioxide.

DIAGRAM 1
Combustion Stages





HEATING VALUES OF FUELS

The amount of heat released when complete combustion occurs is a constant amount per unit of fuel and can be calculated from the quantity of fuel burned. Heating values for electricity and commonly used fuels are shown in Table 1. (For the purposes of comparison, electricity can be considered a fuel.)

TABLE 1
Heating Values

Type of Fuel	Heating Value
No. 2 heating oil	164,000 BTU per Imperial gallon or 38.0 MJ per litre
Propane	112,000 BTU per imperial gallon 26.0 MJ per litre
Natural gas	1,000 BTU per cubic foot or 37.0 MJ per cubic metre
Electricity	3.6 MJ per kWh

Note: 1 MJ (megajoule) = 1,000,000 joules = 948 BTU (British Thermal Units)

HEATING EFFICIENCIES

It should be noted that, although Table 1 lists the heat content of various fuels, not all of this energy will be available as useful heat. The quantity "thermal efficiency" is defined as:

$$= \frac{\text{Useful heat} \times 100}{\text{Heating value of fuel}}$$

In normal operations the thermal efficiency will be considerably less than 100 per cent owing to various losses that occur. These include heat loss due to unburned carbon in the fuel, moisture in the fuel, water from combustion of hydrogen, water vapour in the combustion air, heat loss in the flue gas, unconsumed hydrogen, radiation, etc.

The term "thermal efficiency" describes the steady-state efficiency of a heating system or device. Steady state is the situation when the boiler or furnace has been operating at a fixed firing rate continuously for long enough that all components of the system (boiler or furnace, flue and chimney) are completely warmed up and at a constant temperature.

TABLE 2
Heating System Efficiency

Burner Operation	Average or Typical Thermal or Steady State	Average or Typical Seasonal Efficiency
Oil or gas – on – off	70-75%	55-65%
Oil or gas – Low-High-Low	80	70
Oil or gas – Modulating	80	80

The annual or "seasonal efficiency" will be much lower than thermal efficiency for burners with on-off control because of the additional losses that occur when the burner is off. The air flow will remove heat from the furnace and heat exchanger components and even from the building itself. This heat must of course be replaced.

Seasonal efficiencies can be quite low, especially when a heating plant is larger than necessary. Seasonal efficiencies below 50 per cent are by no means uncommon.

In practice, the seasonal efficiency of a small heating plant, such as for a house, town hall or fire station cannot be measured, but it can be estimated from tests of similar heating plants under controlled conditions. However, the seasonal efficiencies of larger boiler plants (those delivering 10,000,000 BTU/hour or more) can be, and usually are, measured and recorded.

The steady-state efficiency of an existing combustion apparatus can be measured with an inexpensive flue-gas analysis kit such as the Bacharach Fyrite Analyzer. The kit contains a flue-gas thermometer, a flue-gas carbon dioxide sampler and a slide-rule calculator. With measurements of furnace-room temperature, flue-gas temperature and carbon dioxide, the steady-state efficiency can be calculated.

The steady-state efficiency can be improved by adjusting the air/fuel ratio of the burner, increasing the fan speed and replacing dirty air filters. All these measures cost little or nothing.

FUEL CONVERSION

Two things have influenced the conversion of heating plants in many buildings in recent years:

1. The difference in price between the various fuels, primarily oil, natural gas and electricity; and
2. The development of much improved small furnaces and boilers that operate at higher efficiencies in the order of 90 per cent or more.

The calculations necessary to analyse a possible conversion are relatively simple, as illustrated in the following example:

Present system:	No. 2 Oil – average annual consumption 5,000 litres
Estimated seasonal efficiency:	60 per cent
Proposed system:	Natural gas with high-efficiency furnace with an estimated seasonal efficiency of 90 per cent.

The amount of natural gas required for an average year will be =

$$\frac{5{,}000 \text{ litres of oil} \times 38.0 \text{ MJ/litre} \times 0.60 \text{ efficiency}}{37.0 \text{ MJ/cubic metre} \times 0.90 \text{ efficiency}}$$

$$= 3{,}423 \text{ cubic metres of natural gas.}$$

The unit costs of the two fuels can then be applied to compare the annual fuel bills.

Similar calculations can be made in the case of a simple conversion from oil to gas assuming both have the same seasonal efficiency. If a conversion to or from electric resistance heating is being considered, the normal practice is to assume 100 per cent seasonal efficiency for the electric system.

The following examples document the savings achieved through a variety of changes to, and conversions of, heating systems.

NEW LIFE FOR AN OLD BUILDING

At the Dufferin County Court House high efficiency boilers replaced an oversized, inefficient heating plant and saved $8,518 during the first year.

The Dufferin County Court House in Orangeville was built over 90 years ago. The total area of the original building is approximately 1,000 square metres (10,800 square feet). In 1974 a 910-square-metre (9,800 square foot) addition was built.

The old part of the court house contained a heating plant consisting of five oil-fired hot water boilers with a total capacity of 1,750,000 BTU/hour. The domestic hot water heater was also oil-fired. The 1974 addition was heated by two gas-fired hot water boilers, and domestic hot water was heated by electricity.

In recent years, servicing problems with the heating plant in the original building became more and more frequent, and in 1984 it was decided, in the interest of cost efficiency, to convert the system to natural gas supply and to replace the boilers. The equipment chosen was the Hydrotherm "Hydro pulse boiler", which the manufacturer claims has a 90 per cent seasonal efficiency. (Efficiencies as high as 96 per cent have been recorded.) The new heating plant consists of three high-efficiency gas boilers with a total capacity of 450,000 BTU/hour. Certain control changes were also made in order to improve the overall operation. The domestic hot water unit was changed from oil to electric.

Dufferin County staff maintain excellent records of their heating plant operation, and the following cost data reveal the wisdom of their decision to upgrade:

Annual costs before conversion (1983-84)

Oil	$12,305
Gas	5,967
Total	$18,272

Annual cost after conversion (1984-85)

Gas	$9,754

Annual saving $18,272 minus $9,754 = $8,518

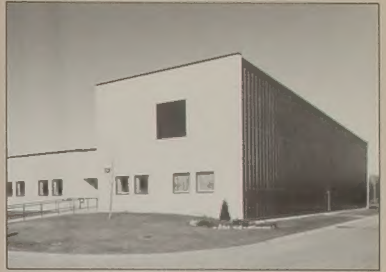
The total cost of the conversion, including modifications to the controls was $19,069.

The payback period = $\frac{\$19{,}069/\text{yr}}{\$\ 8{,}518/\text{yr}}$ = 2.24 years.

This fast payback is due primarily to the high efficiency of the new plant and the probably very low seasonal efficiency of the old, oversized heating system. The difference in cost per BTU of the two fuels is, of course, a factor.

Is the user satisfied with the results? Stuart Smart, County Engineer for Dufferin County, says "Very much so. The savings have certainly been considerable. We are now planning to install four more high-efficiency systems in other buildings that we operate."

OLD ARMY CAMP GETS A NEW UNIFORM



In 1971 a central steam heating system in Craig 1 was replaced with individual oil-fired boilers. In 1983 these were converted to gas and annual savings of over $13,000 were achieved.

The former Canadian Forces Base at Prince Edward Heights near Picton, Ontario, served as an army camp from the early days of the Second World War. The camp consisted of three main buildings and over eighty individual houses. In 1970 the property was taken over by the Ontario Ministry of Government Services (MGS) and transformed into a centre for the developmentally handicapped.

It was obvious to the new owners that the 1940-vintage heating system, which used steam from a central plant, was sadly outmoded and, in 1971 the first step towards modernization was taken. The central plant was taken out of service and individual oil-fired boilers were installed in each building. This presented an immediate saving as operating personnel were no longer needed. In addition, there were no more distribution losses between the central plant and individual buildings.

By 1983 it was apparent that running costs were becoming excessive and it was decided to convert the heating plants in the three major buildings, known as "Craig 1, Craig 2, and the Activities Building" to natural gas.

The building known as Craig 1, which serves as a hospital, was steam heated by two 50-horsepower oil-fired boilers. These were converted to gas. One boiler is now operated continuously, and the second serves as a back-up or to provide additional heat in extremely cold weather. The boilers are operated automatically, on a low-high firing arrangement. Normally the boiler is on low firing, but if the steam pressure drops below a specific value, the boiler switches over to the high-firing rate. The new system has an estimated efficiency of 85 to 88 per cent.

Oil consumption for Craig 1 for the 1983-84 season was 165,387 litres at a cost of $46,804. In the 1984-85 season 180,230 cubic metres of gas were used at a cost of $33,491, or a saving of $13,313.

Craig 2, used primarily for hospital administration, employed two 20-horsepower hot water boilers. These were converted to natural gas for a first-year saving of $4,733.

The Activities Building tells a similar story. It has a hot water system served from two 30-horsepower boilers. Conversion to gas yielded an annual saving of $10,013.

The total cost of the renovations to the three buildings was $105,000. With an energy saving of $28,059 for the first year of operation, the payback period is under four years.

Reg Vincent, a regional Mechanical Inspector for the Ministry of Government Services (M.G.S.), is located in Kingston, and his duties encompass the supervision of M.G.S. projects in the district. He notes that the conversion to natural gas has worked out very well and that his own staff have confirmed the short payback period that had been estimated at the time of conversion.

BIG SAVINGS FROM WASTE HEAT

Sometimes it is possible to improve the overall energy efficiency of a heating plant without changing the boiler or the fuel supply. The Empire Hotel in Timmins found that its natural gas bills for heating dropped by over 26 per cent in the first 11 months when certain changes were made to the system (see Figure 2).

In December 1985, new water heaters along with new kitchen equipment were installed. At the same time, a heat recuperator was installed on the exhaust from the hot water boiler. This device, a Thermal Energy Saving System or TESS, allows the flue gases to make three passes through a heat exchanger. The unit also condenses the water vapour in the flue products. The heat of the exhaust gas is transferred by the heat exchanger to the domestic hot water system, in effect, preheating it. The TESS unit was developed by the installing contractor, Roger Michaud Services of Timmins.

As a result, the overall efficiency of the heating plant has increased from 60 to 90 per cent. The total cost of the complete renovations to the hotel's energy systems was approximately $30,000. For the first 11 months of 1986, the energy savings totalled $11,073.50. This gives a payback time of approximately 2.5 years.

Jack Laferrière, owner of the Empire Hotel feels the results have been excellent, "It's cut my heating bill almost in half, and there's been no maintenance required. I took out a loan to finance the cost of the capital equipment. Now I pay the bank instead of the gas company, so my cash flow is unchanged. But once the unit pays for itself, in two to three years, all the savings come back to the Hotel."

Figure 1
NATURAL GAS CONSUMPTION

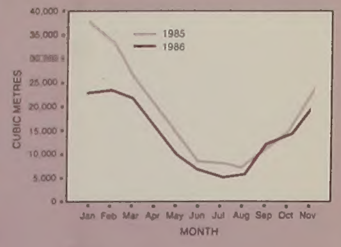
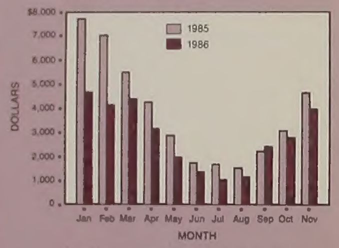


Figure 2
NATURAL GAS COSTS



Note: New system was installed December 1985

Empire Hotel, Timmins. Installing a heat recovery system on the boiler exhaust cut natural gas bills by 26 per cent.

PROJECT SUMMARIES

Dufferin County Courthouse, Orangeville
Total Floor Area: 1,910 square metres (20,600 square feet)
Cost of Project: $19,069
Annual Savings: $ 8,518
Payback: 2.24 years

Prince Edward Heights, Picton
Total Floor Area: Three buildings, 16,152 square metres (173,860 square feet)
Cost of Project: $105,000
Annual Savings: $ 28,059
Payback: 3.7 years

The Empire Hotel, Timmins
Total Floor Area: 5,600 square metres (60,280 square feet)
Cost of Project: $30,000
Annual Savings: $12,000 (estimate)
Payback: 2.5 years

For further information contact:

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Combustion:

Fuel & System Efficiencies

Prince Edward Heights near Picton, has seen many changes to its function and its heating equipment. Most recently, conversion to natural gas has resulted in annual savings of $28,059.

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